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A FEASIBILITY STUDY AND DEVELOPMENT PROGRAMME FOR CONTINUOUS DILUTION GAUGING

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ABSTRACT

The applications of continuous dilution gauging are considered and the Consultants discuss practical feasibility. A simple development programme is recommended and a specification is given for Stage 1 equipment; this would gauge automatically at a structure for calibration purposes.

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1. INTRODUCTION

Dilution gauging is rapidly becoming a standard technique for measuring streamflow. The most recent and comprehensive report on the subject is published by the Water Research Association (1) and their manual is the result of three years work by the Dilution Gauging Team. On the disbanding of the W.R.A. Team, two of its members, P.H. Hosegood and M.K. Bridle, joined the Institute of Hydrology as Consultants for a month to consider the problems of continuous dilution gauging.

There are no published accounts of work on automatic or continuous dilution gauging, although some automatic equipment was used by the University of Newcastle-upon-Tyne (2). The Water Resources Division of the United States Geological Survey report (3) that they are working on the topic, but have no results available to date and know of no other experiments in this field.

The application and feasibility of continuous dilution gauging is examined therefore in the context first of the Institutes' own work and second in general, as an alternative to flow measurement structures.

2. APPLICATIONS

There are four applications of continuous dilution gauging which should interest those concerned with streamflow measurement.

Calibration of gauging structures

Dilution gauging, which can measure discharge to within 2% is becoming the established method of confirming the stage-discharge relationship at a structure or river section. However, considerable time can be wasted waiting to measure higher flows and in the case of very 'flashy' catchments it may be impossible to catch the peak flows. It would therefore be extremely useful to develop an automatically initiated dilution gauging system that would operate long enough to define the relevant part of the stage discharge relationship.

Flood discharges at structures

Measurement at a structure of flood discharges which have long return periods (i.e. greater than, say, 3 years) requires expensive construction. It is not usually possible to estimate the probability of such a flood with any great accuracy. Hence it is quite useful to be able to measure such discharges automatically with continuous dilution gauging.

Short term streamgauging

There are studies within the Institute where a continuous gauging is required for only a short time. This particularly applies to groundwater studies and the proposed snow catchment studies. There are obvious advantages in having portable equipment capable of continuous gauging for up to 2 - 3 days.

Secondary and inaccessible gauging stations

If the equipment could be designed to be sufficiently robust and reliable, a portable continuous gauging station that required no stilling well would be most useful in inaccessible areas, particularly overseas. There would also be an application in setting up short term secondary gauging stations for correlation with a long term base station. For this application the equipment should be capable of operating unattended for one month.

3. CONSULTANTS BRIEF

The Consultants were asked to consider the following topics in their report.

Feasibility

a) In small upland streams, e.g. at Plynlimon; mean flow 0-1m^3/s.

b) In medium and large rivers; mean flows 1-20 and >20m^3/s.

c) In inaccessible areas overseas, for small, medium and large rivers.

Methods: what are the recommended methods?

a) Sodium chloride and conductivity.

b) Sodium dichromate and auto analyser.

c) Radio active tracers such as tritium.

Problems: what are the problems and limitations inherent in each method? Consider for instance:

a) Source of power

b) Pollution

c) Reliability

d) Flow range measureable

e) Chemical quantities and mixing lengths.

4. CONSULTANTS FEASIBILITY REPORT

Nomenclature

For a constant rate gauging the discharge is given by:-

$$Q = \frac{C_1}{C_2 - C_0} \times q \times 10^{-6}$$

Where Q = Stream discharge (m^3/s)

q = Rate of flow of injection solution (ml/s)

C_1 = Concentration injected ($\mu g/l$)

C_2 = Downstream concentration level ($\mu g/l$)

C_0 = Background level of injected solution naturally present in the river ($\mu g/l$)

Dilution Gauging Techniques

1) Gulp method

For continuous gauging of rivers with a changing discharge, the gulp method would be impractical for the following reasons:-

a) The injection apparatus would be complex and dependent on a sophisticated timing mechanism.

b) As the sampling pulse time is not proportionate to discharge, a complex variable sampling schedule would be required. This would be difficult to automate.

c) Under certain discharge conditions pulse overlap at the sampling station could occur, which would invalidate the measurement.

d) Accurate integrated sample collection over long periods requires mains electricity.

2) Constant rate method

However, the constant rate method using sodium dichromate, with slight modification to the conventional equipment would be capable of gauging continuously a fairly stable discharge but the continuous measurement of a discharge that is fluctuating would require further modification and some additional equipment. For all ranges of flow a standard procedure could be adopted for the collection of the background (C_0) and downstream (C_2) samples and would consist of a continuous sampling device, such as the Rock and Taylor equipment. The injection apparatus for the dosage of the tracer solution would have to be adapted for the particular set of circumstances likely to be encountered.

Tracers

Ideally, a tracer used for dilution gauging should have as many of the following properties as possible.

It should:-

(a) Be stable and inert to light, bacterial and chemical attack, chemical association and loss[x] into river bed, banks, suspended materials and aquatic vegetation.

(b) Be non-toxic at the concentrations which result downstream.

(c) Be highly soluble and therefore homogeneous in solution.

(d) Have no large or variable concentrations naturally present in water.

(e) Be capable of accurate analysis at low concentrations.

(f) Be inexpensive.

(1) Sodium Dichromate

There are no known chemical tracers which meet all the above requirements, but sodium dichromate certainly meets the last four and is the tracer which the W.R.A. Gauging Unit finally decided upon for routine gaugings. No toxicity problems have arisen to date, since gaugings have only lasted a few hours, but injecting dichromate continuously will create fresh problems. Although fish have been subjected for long periods to dichromate concentrations similar to those encountered during gaugings, little work has been carried out on the effects of dichromate on their food, but Klein (4) states "water fleas (Daphnia magna) are adversely affected by as little as 0.1 mg/l of Cr^{6+} present as sodium chromate". However, this does not necessarily imply that an equivalent amount of Cr^{6+} in the dichromate form, would have the same effect, even under identical conditions. If continuous

[x] This term is preferred since any of several different mechanisms e.g. absorption, adsorption and ion exchange can occur.

gaugings are carried out on headwaters, subsequent dilution of the dichromate downstream may render the method acceptable to the authorities concerned.

All of the 'common' salts (NaCl, KCl, $MgSO_4.7H_2O$, LiCl, etc.) which have been used as tracers had various limitations even under ideal conditions and when considered for continuous gauging must be discarded simply on account of the high volumes of tracer solution which would be required.

(2) Isotopes

Radioactive isotopes are in many respects superior to sodium dichromate especially in polluted rivers and those with large amounts of suspended solids, where, even if there is no loss of dichromate, analysis is made more difficult. Tritium is, of course, the 'perfect' tracer but has the disadvantage of a 12.26 year half-life. Isotopes are worth serious consideration, but public opinion, cost and difficulty in safeguarding a potentially dangerous injection system may render them impracticable.

(3) Dyes

The Americans have almost exclusively used the xanthene dyes and in particular rhodamine WT, pontacyl pink B and rhodamine B for gauging. However, permission to use these dyes has not been obtainable in this country since their toxicity is in dispute and their feasibility under practical conditions is unknown.

The Proposed Techniques

1. Site and mixing length

Before any continuous gauging can proceed, preliminary work on the proposed reach (see Manual (1)) must determine the suitability of the river for dilution gauging purposes and the maximum mixing length for the range of discharge to be encountered. This will define the reach and enable the positioning of the background injection and sampling sites. Generally speaking, the maximum mixing length will occur when the river is at its lowest flow, but mixing length determination is invariably a case of trial and error.

The mixing length can easily be checked once a continuous gauging is running, by taking several samples across the river at the downstream sampling site and evaluating the sample concentrations for uniformity. This check on mixing length would be carried out on inspection visits of the gauging station; one assessment of mix for each major change in discharge level would suffice. If the mix % by Schuster falls below 98% for any level of discharge, the downstream sampling station should be re-sited further downstream. Results previously obtained at this level of discharge should be discarded as mixing was inadequate. This means that it is essential to evaluate mixing over a wide range of discharge as soon as possible.

2. Background sampling

The background sampling equipment would be standard and of simple design, irrespective of size or range of discharge, since this water merely serves as a reference blank for the subsequent analysis. Sufficient water (10 litres) must also be collected for the dilution of the concentrate (C_1), the diluted concentrate subsequently being used as a reference standard.

The primary object of the equipment for background sampling would be to take a fairly consistent volume sample, say every hour, that would be bulked in a single container. This would represent an integrated sample of the background condition during the gauging period. The conventional Rock and Taylor liquid sampling machine would be capable of this task. Should a more precise knowledge of the background fluctuation of the tracer in use be required, discrete sampling at pre-set time intervals would be necessary. However, under natural conditions dichromate is seldom present in river water, although an apparent background exists due to colour. The spurious background effect is invariably steady, thus obviating the need for discrete samples. Should discrete sampling be required, the design of the equipment would be identical to that described in section 4.4.7 for downstream sampling. Discrete samples should be approximately 100ml in volume and a minimum of 10 litres is necessary for the bulk, integrated sample.

3. Dose rate

The linear response for Cr^{6+} by the Auto-Analyzer method (1) is from 20-100 µg/l.Cr^{6+}, therefore a dose rate calculated to give a plateau condition of 60 µg/l would allow for a plateau fluctuation of ±60%. For all systems of injection, the dose rate should be calculated to give the above rise and this would enable a stream flow change of ±60% to be satisfactorily gauged without adjustment to the dose rate.

If, during the course of a gauging period, the plateau level exceeds the limits for a sufficient duration to give a downstream sample (C_2) that is not within the analytical range, a gauging result can still be obtained by dilution or reconcentration of the C_2 sample. Sample dilution is a simple procedure but reconcentration by the butanol method requires some practice (1). Some loss of gauging accuracy can occur from these laboratory techniques of sample recovery for analytical purposes, but this really depends on operator skill. For this reason, reconcentration should not be practised as a regular feature.

4. Injection system for small rivers with fairly stable flow

For this type of gauging the dose rate would be set at the beginning of the gauging period by the use of the appropriate jet size. The jet size would be selected in accordance with an estimate of the anticipated mean streamflow expected during the period. For each gauging interval (hourly or daily) during the unattended period, the dose rate (q) must be constant and known. Field confirmation of this is necessary as flow from a jet can vary (±4%) depending on solution density; also, vicosity is affected by temperature.

To achieve a steady state condition at the downstream sampling station of 60 µg/l. of Cr^{6+} for a discharge of 1 m^3/s would require a dose rate of 17 ml/min. of stock solution (600 g/l. $Na_2 Cr_2 O_7 . 2H_2O$) or approximately 24.48 l/day. Therefore, the conventional Mariotte bottle of 60 l capacity would be capable of delivering an adequate injection for a streamflow of 1 m^3/s for an unattended gauging period of 2 days. For discharge less than 1 m^3/s the stock solution could be diluted or, alternatively the dose rate reduced, thus increasing the gauging

duration.

The concentrate (C_1) should be taken at the beginning of the gauging period, after the solution has been thoroughly mixed in the bottle. It can be taken either by extracting a sample from the Mariotte bottle before securing the cap, or from the outlet. If taken by the latter method, care should be taken to see that the tap is flushed before sampling, as crystals of sodium dichromate can form by evaporation in the outlet and contaminate the sample.

5. Injection system for medium and large rivers

Rivers of stable flow, regardless of size of discharge can be gauged using a predetermined, fixed injection rate. For rivers of changing discharge, a variable injection rate proportionate to streamflow is necessary. Any change in injection rate must occur well before sampling time, so that stable plateau conditions exist when the C_2 sample is taken. This rules out a variable injection changing continuously with stream flow, since it would be impossible to relate q to the C_2 sample. However, a 'stepped' injection that triggers off either an increase or decrease of dose rate for a predetermined streamflow bracket may be feasible. This means that in practice the dose rate must be linked either to stage height or velocity; unfortunately neither of these parameters are directly proportionate to discharge.

The dose rate could be controlled by an adjustable micro-valve, persistaltic or displacement pump each capable of variable speed. Small jets i.e. micro-valves can be operated by mechanical means only, whereas pumps require a stable electrical supply. Jets have the disadvantages of becoming easily blocked by either foreign matter or crystallisation, and their performance is very susceptible to temperature and viscosity. A peristaltic pump tends to be self-cleaning but may suffer from the effect of temperature. By definition a displacement pump should have none of these inherent disadvantages and if the pumping rate could be recorded satisfactorily to give q accurately, this would obviate the need for a recording device on the tank.

6. Storage of tracer

A storage tank to hold sufficient tracer for the gauging period is the primary requisite of the injection system. The general requirements for the tank are as follows:-

(a) It should be cylindrical, small in base and tall, so that its outflow may be accurately recorded.

(b) For rigidity it will probably have to be made of metal, with an interior coating which is inert to the tracer. Fibre glass would be ideal construction material.

(c) A mechanical mixer should be incorporated in the tank.

(d) A detachable lid is necessary for inspection purposes and recharging with tracer solution.

(e) The outlet should be situated near the bottom and there should be a sump to collect sediment.

(f) It should be insulated against temperature variations.

(g) A sensitive recording device to continuously measure outflow is the most important feature.

(h) An in line filter is necessary to remove sediment from the river water to be used for mixing up the tracer solution.

In a large tank, a sight glass should be avoided, as it would be difficult to mix the contents of the glass with the bulk in the tank.

In the case of sodium dichromate the concentration in the tank should not exceed 600 g/l. and tank sizes should be budgeted for accordingly. Above this concentration, the increase in viscosity seriously affects jet flow (assuming a jet was used) especially at the lower temperatures. Also, the density of the solution is 1.4 at 20°C and an increase in this figure may create mixing problems once the tracer is in the river.

The tracer should be mixed in small quantities using filtered river water and after mixing should be refiltered before being pumped into the tank. This removes any extraneous matter present in the bulk chemical and reduces the risk of jet blockage.

When the tank is filled and thoroughly mixed the C_1 sample can be taken.

The size of the tank depends on the discharge to be gauged. For example a mean discharge of 10 m^3/s, dosed for a rise of 60 µg/l Cr^{6+}, 54 gallons a day of stock solution would be required. Hence, for a 30 day gauging period, tank capacity of 1650 gallons is necessary.

7. Downstream sampling

The downstream sampling equipment is the same, regardless of river size or type of injection. It must be sited at a position of satisfactory mix and several different methods could be adopted for collecting the C_2 sample, depending on the interval measurement required.

(a) Discrete samples at fixed time intervals to give, for example, hourly flow measurements.

(b) The above system, but with samples manually bulked in the laboratory to give a total discharge measurement over a period of say 1 day.

(c) Automatic integration by collection of a consistent volume sample. This would give total flow measurement over the integrated period of say 1 day and then step on to the next period.

All the above sampling systems could be adapted from the Rock and Taylor equipment (see Appendix A).

An alternative system of downstream sampling, indeed the ideal method in many instances, would be on site analysis by continuous pumping of the downstream sample direct to the analytical apparatus (e.g. Auto-Analyzer). This would require bankside installation of the equipment, housed in a semi-permanent building and operated from mains electricity.

By using this technique of sampling a continuous record of discharge would be obtained similar to a hydrograph of stage height.

This method has the advantage of analysing a fresh sample, hence the analysis for Cr^{6+} would be much simplified. Difficulty could be experienced in arranging for the insertion of both the diluted C_1 reference standard and the C_0 sample used as baseline. It must be noted that this method can only be used if the C_0 value is absolutely steady, since a bulk background sample would have to be taken prior to the commencement of a gauging and subsequently be automatically sub-sampled for analysis at regular intervals throughout the gauging period.

The ultimate technique would be to provide a fresh background sample phased to the C_2 sample being analysed. This could be arranged by utilisation of the hydraulic slope to deliver water via a pipe from the background site to give a continuous C_0 sample for analysis at the downstream site. This method would give the true rise in concentration at the downstream site and theoretically, the best answer.

In the past, recorder base line drift has been a problem, but this could be overcome by the direct print out of the colorimeter signals. The print out could be arranged for computer processing, thus avoiding the tedious and lengthy task of obtaining individual readings from a chart.

At the moment, reagents used for the analysis are prepared daily since they are unstable and this would require a fresh approach.

8. Power requirements

Mains electricity at the injection and sampling sites would be ideal, since a dosing pump could be used for injection and on site analysis would be possible. The supply of background heat to protect both instruments and associated equipment from adverse weather conditions is essential and could be easily arranged from mains supply.

In the majority of cases, battery operated equipment will be necessary. Battery efficiency will have to be maintained, which may prove difficult over

long periods, especially as power will be required for background heating. To maintain a high battery charge and hence consistent performance of apparatus it has been suggested that a water wheel or windmill be used to operate a small generator. This will obviate the need for frequent battery replacement and gauging duration will thus be limited to the volume of solution required for injection.

9. Accuracy

Systematic errors could occur in the gauging results and experience has shown that the injection rate is the most likely source. A check could be made to determine whether or not a systematic error exists by carrying out a simultaneous gauging using different equipment. This technique has already been used successfully by comparing radioactive and chemical dilution gauging (5).

The random error will again depend primarily upon the reliability of the injection rate. Other sources which are small in comparison, are the bulking of the C_2 sample either automatically or manually and the chemical analysis. An estimate of the random error in a gauging where only a bulked C_2 sample is used would probably be <5%. If 24 hourly samples contribute to the daily value, the error would obviously be reduced, and would be about 2%.

10. Operating problems

In addition to the problems already mentioned, the following points should be noted.

The dichromate solutions, particularly the downstream samples, must be kept in the dark, as they deteriorate in light. Further work is required on the preservation of samples for long periods. The prevention of sample evaporation during storage is also important.

Care should be taken when handling concentrated dichromate solution as it can cause skin ulceration and protective gloves must be used.

Contamination of the background and downstream samples by the concentrate solution must be avoided. Also, spillage of the latter when replenishing the tank, should be avoided, as this would seep into the river and give an erroneous result.

Costs

1. Equipment

A complete gauging station would require an automatic sampling device for background and downstream sites, the total cost being around £1,000. The injection equipment, comprising an adequate tank and dosing system with recording attachment, could cost from £500 to £1,000 depending on the size of installation. If mains electricity is available, on site automatic analytical equipment at the downstream station would obviate the need for both the above samplers. The cost for this system would be in the region of £1,500 but would probably be the cheaper, as no further analytical work would be required. All equipment would require some form of housing.

2. Running costs

In the past, sodium dichromate dihydrate, ($Na_2 Cr_2 O_7.2H_2O$) has been used in small quantities. However, large quantities of commercial grade sodium dichromate are obtainable in the anhydrous form ($Na_2 Cr_2 O_7$) from Albright and Wilson at a price of 10p per Kg. for 5 ton lots (1 cwt. bags).

Using the anhydrous form would increase the Cr^{6+} content by 4.8% in the stock solution and consequently a smaller dose rate would be required and the tank capacity could be reduced.

At the above price, the daily cost would be £1.30 per m^3/s and hence 10 m^3/s would cost £13 per day. Expenditure on the tracer is the prime factor in running costs, e.g. the cost of sodium dichromate would be £4,750 p.a. for gauging a mean flow of 10 m^3/s.

A possible alternative to chemical tracers is isotopes, especially tritium (see Appendix B). The cost of tritium at a level of 5000 tritium

units (recommended for accuracy and low cost analysis) could be as low as £1,370 p.a. for the above discharge. However, the cost of analysis for daily discharge totals would be £274 p.a. (75p per sample) and for hourly discharge values £6,580 p.a. We are unable to comment on the field requirements for tritium gauging, but believe the equipment would be similar, except that on site analysis would be impossible.

Conclusions

1. General

From this study it is our opinion that continuous dilution gauging is feasible, but may not always be economical or practical. The main problems to be resolved are bankside instrumentation and acceptance of a sustained level of tracer in the river.

At the moment sodium dichromate is the best chemical tracer available. New tracers with superior properties may be found, but it is unlikely that they will rival chromium for price. If daily discharge totals are required, tritium would be far cheaper, but for the evaluation of discharge on an hourly basis the position is reversed. Chromium also has the merit of a relatively simple analysis that could be undertaken in remote areas, e.g. overseas.

2. Calibration of gauging structures

This is the simplest application of continuous dilution gauging. We recommend that this should be considered as the first stage in the development of continuous dilution gauging equipment. Notes and a specification, which are to be the basis for further development, follow this report.

3. Measurement of floods at structures

This is the second stage of development and the apparatus would be basically the same as in stage one, but must be capable of measuring greater discharges and a wider range of flows. This can be achieved by designing a larger Mariotte and improving analytical methods of

reconcentration. However, considerable thought must also be given to the problems associated with leaving the equipment unattended and inoperative for long periods of time.

4. Short term stream gauging

The preceding two sections were concerned with continuous gauging at a structure which already has a stilling well and a pre-determined stage-discharge relationship and permits automatic triggering. Continuous stream gauging over a period of 2 - 3 days would only be possible with the same type of equipment in small streams of $\frac{1}{4}$ - $\frac{1}{2}$ m^3/s flow. It would probably not be worthwhile to attempt including automatic triggering in this case.

The main application under this heading would be the measurement of small groundwater fed streams.

5. Secondary and inaccessible gauging stations

Although it would be feasible to develop a system that would continuously gauge medium and large rivers over periods of up to a month, we do not consider it a practical or economical project at present. Approximate costs can be summarised as follows:-

	(a)	(b)
Background and downstream sampling	£1,000	
Injection equipment, with tank	£1,000	£1,000
Auto-analyzer equipment		£1,500
	£2,000	£2,500
Annual running cost for 10 m^3/s river		
Sodium dichromate		£4,750
Tritium (inc. laboratory analyst for daily mean flow)		£1,644

The main problems associated with developing the equipment on this scale are:

1. Cost
2. Continuous pollution; permission is only likely to be given if there is considerable dilution immediately downstream of gauging reach
3. Constant rate injection of relatively large quantities of tracer
4. Variable injection rates, governed by flow conditions
5. Chemical storage and decomposition
6. Power supply
7. Development of auto analyzer to operate reliably and unattended for a month.

5. PROPOSED DEVELOPMENT PROGRAMME

Following the recommendations of the Consultants a development programme is proposed in 3 stages.

Stage 1: Calibration of Structures

The standard 60 l Mariotte bottle and Rock and Taylor samplers form the basis of the equipment. Maximum discharge will be 15 m^3/s and only a five fold flow range will be possible. The apparatus will be triggered at a pre-determined stream flow and will operate automatically, sampling at intervals of 5 - 15 minutes, for periods of up to about six hours. Sample bottles will later be collected for laboratory analysis and the apparatus re-set to gauge a larger discharge.

Stage 2: Flood measurement at structures

The method developed in Stage 1 should be improved in the following ways:-

(i) Maximum discharge gaugable to be increased to 75 m^3/s by designing a larger Mariotte bottle.

(ii) The flow range gaugable with one injection rate should be extended by improving reconcentration methods.

(iii) The equipment should be capable of operating after much longer periods of waiting.

Stage 3: Short term stream gauging

The equipment would be similar to that of Stage 2 but with the following differences:-

(i) Sampling equipment would not be housed in a recording hut. All equipment should therefore be more compact, portable, tamper-proof and weatherproof.

(ii) Number of sampling bottles would probably have to be increased.

(iii) Automatic initiation of gauging would probably not be necessary.

Problems associated with Stage 1 development

1. Automatic switching on and off of Mariotte bottle.

2. Measurement and recording of injection flow rate.

3. Transmission of signals from recorder hut to injection point up to ½ mile away.

4. Attaching triggering device to Leupold and Stevens recorder mechanism.

5. Designing an eventmarket to record beginning and ending of sampling on chart.

6. Designing a master timing system linked to recorder clock.

7. Adapting Rock and Taylor sampling equipment.

8. Including a safety cut-off switch if stream flow falls rapidly during injection.

6. SPECIFICATION FOR STAGE 1 EQUIPMENT

Purpose

At Plynlimon there will be six steep stream structures designed on the basis of research done at H.R.S. As these are the first structures of their kind in the country it is desirable to check the theoretical calibrations by dilution gauging over as wide a range of flows as possible.

The extreme flashiness of the streams at Plynlimon makes it difficult to be on the spot at the right time to do the dilution gauging manually. For instance a recent flood had a time to peak of two hours, during which time the flow at Cefn Brwyn rose from 1 to 17½ cumecs.

It is hoped that automatically actuated apparatus will measure discharge at, say, 5 min. intervals beginning at a pre-determined flow and over a five fold flow range. By setting the triggering flow to progressively higher discharges it is hoped to calibrate the structures over the whole range of discharge.

It is obvious that the equipment will have to stand inoperative for considerable periods of time whilst waiting for a sufficiently high discharge to activate the gauging.

Range of discharge

The rate of injection, q, will be preset for each gauging and so the range of discharges, Q, that can be measured depends on the analytical range possible with the samples. The analytical range is from 0.1 to 0.02 p.p.m. giving a five fold dilution and hence discharge increase of five times.

The continuous gauging must be capable of measuring the whole hydrograph, (within the five fold range) including the rising stage, peak and recession. The discharges measured on the recession will be most useful for calibration.

Discharge ranges are as follows:-

	Cusecs	Cumecs
I	1 - 5	0.025 - 0.125
II	5 - 25	0.125 - 0.625
III	25 - 125	0.625 - 3.125
IV	125 - 625	3.125 - 15.625
V	625 - 3125	15.625 - 78.125

Rate of rise of discharge

The rapid rise in discharge experienced in Plynlimon streams is illustrated in the following figures which are for a storm in August 1969.

Gauging Station	Time to Peak	Initial Discharge	Peak Discharge
	Hrs	cumecs	cumecs
Cefn Brwyn	2	1	17.5
Severn Flume	2¾	1	8.75
Iago	2	0.12	1.6
Tanllywth	2	0.16	4.0

The suggested rates of rise to be allowed for in each structure are as follows:-

Structure	Max. Discharge	Max. Rate of Rise in Discharge
	cumecs	cumecs/hr
Tanllwyth, Iago	4¼	2½
Hafren, Cyff	10	3½
Wye, Hore	14½	5
Severn Flume	42	6
Cefn Brwyn	65	10

The equipment should be able to measure discharges increasing at all these rates.

Injection equipment

1. The injection equipment should be:-

   (i) Compact and portable by two men. It should not require very accurate setting up.

   (ii) Robust and weather proof.

   (iii) Vandal and tamperproof, so that it can be left unattended for long periods. (No great problem is anticipated at Plynlimon where vandalism is very rare).

2. The injection rate, q must be measured and recorded to an accuracy of better than 1%. The injection rate may be monitored by single suspension strain gauge transducer (for instance a ring type tension gauge by Langham-Thomson Ltd). An analogue linear displacement recorder would be housed in the injection or recorder hut to record the weight change. The cnart should have a minimum width of 4".

Some problems will occur when determining volume by weight and these are as follows:-

(i) Density will vary with different concentrations of injected solution. This can be overcome by filling the bottle with solution to an accurately known volume (preferably marked in the neck of the bottle, where the cross-section is small). This will give a datum point for the conversion of recorded weight to volume.

(ii) However, the volume of solution will change with temperature and a correction should be applied. This could be achieved by determining the datum point (mentioned above) for a range of temperature (1 - 20°C).

A sophisticated method that would be independent of temperature is to have sensoring probes spaced at known volume intervals down the sight tube of the bottle. A sufficient number of these would give the injection rate or alternatively a few incorporated with the above weighing method would do the same.

The dose rate should be set at the upper limit of the analytical range (100ug/l) for the discharge at the start of injection.

3. Injection nozzles in Mariotte bottles should be calibrated in the laboratory so as to give an indication of the flow rate prior to gauging.

4. Injection equipment will be positioned 400 - 800 yds. upstream of recorder hut at each structure and will be connected by cable to timing mechanism in recorder hut.

5. Injection nozzles must not block up during long periods of lying idle whilst loaded with chemical e.g. by crystallisation of $Na_2Cr_2O_7 2H_2O$.

6. Nozzles must not be knife-edged at exit hole.

7. Sight glass and nozzle seals to be standard 'O' ring type seals of the same size.

Sampling equipment

1. This will be situated inside the existing recorder huts and the equipment should not occupy a plan area greater than about 3' x 3'. Maximum pumping head will be about 15ft.

2. Sample size: 100 ml (but 50 ml would be adequate)

3. Overall sampling period: up to 2 - 3 days depending on the maximum number of bottles possible and the sampling interval.

Normal period for calibration purposes, up to 6 hours at 5 or 6 min. intervals.

4. Sampling intervals: There should be a facility for adjusting the sampling time interval to cover any of the following:-

5 or 6 min
10 "
15 "
30 "
1 hour

Probably this could be best accomplished by an interchangeable set of gear trains.

5. Number of bottles:

72 would be best
48 would be adequate

6. Volume accuracy of sample: not important

7. Timing accuracy: Important to maintain a consistent time interval between samples and a consistent sampling time in order that discharges measured by dilution can be accurately related to those measured by the chart recorder, even during rapidly changing discharges.

Timing

1. The time of the first and last sample must be recorded on the Leupold and Stevens chart recorder accurate to within ±3 min. of chart recorder time.

2. The interval between sampling should be consistent within ±1 min.

3. Actual time of pumping for each 100 ml sample must be consistent and accurate to within ±1 min.

Triggering mechanism

1. Must be activated by float or recorder movement of Leupold and Stevens chart recorder and preferably be adaptable to other types of recorder.

2. Must be activated at a pre-determined preset stage corresponding to discharge in the range suited to the injection nozzle being used.

3. Mechanism must not interfere with chart recorder operation. Extra force from float required to operate triggering mechanism must not be greater than 45 g (app. 1 mm of float displacement).

4. Trigger mechanism should be designed to operate in both directions. i.e. switches Mariotte tap open if activated by rising stage and closed if activated by falling stage (only by stage change, not oscillations). (Likewise, switches timing mechanism on if stage rising: off if falling). Mariotte tap operated (opened or closed) by electrical impulse generated over ¼ mile away.

5. Trigger mechanism acts as master switch - switches on not only injection but also master timing mechanism and injection rate monitor.

Overall accuracy of gauging

The cumulative errors must not be greater than 2 - 3%.

Power

Batteries are required as no mains supply are available. Some form of on site charging should be considered.

Sequence of events

Operation	Cause	Time (Min)	See paragraph
1. Beginning of injection and timing sequence	Triggering mechanism at preselected stage	0	6.7
2. Beginning of sampling	Timing sequence	≈60	6.5
3. Mark on Leupold and Stevens chart	Timing sequence	as above	6.6
4. Regular sampling at set interval	Timing cam on auto-sampler	60 - 200	6.5.4
5. Last sample bottle filled. Sampler stops. Mark on Leupold and Stevens chart	Timing device on auto-sampler	≈ 200	6.6.1
or Sampler stops Mark on Leupold and Stevens chart	Timing sequence halted by low flow	any time	6.7.4

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P.H. Hosegood, P.R. Sanderson, M.K. Bridle. W.R.A. (ILR No.34) 1969.

2. Private Communication with V.K. Collinge, Water Resources Board.

3. Private Communication with R.W. Carter, Chief, Surface Water Branch, Water Resources Division, U.S.G.S.

4. River Pollution. Vol. 2, L. Klein, Butterworths, 1962.

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APPENDIX I

Notes on a meeting held on 9th October, 1969 at Institute of Hydrology to discuss dilution stream gauging apparatus.

Present: C.A. Taylor of Rock and Taylor
Messrs. Hosegood and Bridle (feasibility study consultants)
M.T.H. Key, Institute of Hydrology, Mechanical Engineering.

The problems of sampling and injection were discussed at length, the conversation ranging over sampling accuracy, period, quantities, ditto for injection. Mr. Taylor said that all these requirements were feasible "at a price for development and design", no figure being quoted.

Further discussion centred on Rock and Taylor standard products modified to suit, and the outcome was that it seemed a standard 48 day continuous sampler, with modified clock cams to sample into 32 bottles would be satisfactory, giving 1 sample/hour for 24 hours into one bottle before stepping on to the next. Accuracy of sample would be achieved by fitting a U tube volumetric sample collection chamber or a T tube (to facilitate cleaning). Pumping would be a separate device, a Rock and Taylor type peristaltic pump. The costs of the above items standard are:-

Continuous sampler	£240	48 bottles one step on/day
Pump	£110	

When asked by Mr. Hosegood to give an estimate of a set of sampling apparatus on these considerations, Mr. Taylor said under £500 to cover cost of development and design of modifications.

Continuous dosing was considered on the basis of a low output Rock and Taylor pump. Mr. Key recommended that Rock and Taylor could, at little or no cost to themselves run pumps on test at the factory under varying temperature conditions and accurately observe volume delivery over accurately measured time. (This exercise could be of commercial advantage to them anyway for publishing specifications).

One important background problem theme throughout had been 30 days power supply. Mr. Key quoted his experience with previous Rock and Taylor stream samplers of 14 day period and suggested that a separate exercise may be necessary to design and build a water wheel driven generator battery charger. Mr. Hosegood said that although 30 days would be a highly desirable period, 14 days could be acceptable.

M.T.H. KEY

APPENDIX II

Extract from letter by D.B. Smith, Wantage Research Laboratory, (A.E.R.E.) dated 14th October, 1969.

"I have looked at the problem of constant river gauging with tritium, particularly with reference to accuracy and costs.

The following figures are of interest:-

10 cumec flow

Increase tritium in river by:-	Amount/day (24 hours)	Cost tracer/day
500 TU	1.5 Ci	£2.25
1000 TU	3 Ci	£4.50
5000 TU	15 Ci	£22.50

River background would vary from river to river. A ground water fed stream like the Lambourn or other chalk rivers may be 30 TU, while a surface fed river may clearly rise to the tritium content of the rainfall (variable with season, currently 200 to 400 TU) but in practice it is usually appreciably less than this and a current value of 150 TU would be more typical.

At 500 TU, one would have to measure the background. The background could easily be sampled upstream of injection and would vary slowly so that samples need not be 'phased' with downstream sampling. But 150 TU could only be measured by electrolytic reconcentration and liquid scintillation counting and the cost has not been defined. I guess the electrolysis would cost £10 and the scintillation counting 75p per sample.

Measurement at 500 TU would probably also require reconcentration or measurement direct on a gas proportional counter (cost of the order of £20). It could be done in the scintillation detector, but would appear as about 1½ counts/min. above a background of 6cpm and I doubt if one could give a value to ±10% with any confidence.

At 1000 TU, this measurement should be possible to better than ±10% and it may not be necessary to measure background daily except in times of very variable

flow. This would cut the cost.

At 5000 TU, the background would only be needed periodically and a reasonable accuracy could be obtained.

From a health point of view, a person drinking water at the rate of 1.5 litres/day (an additional 1 litres arises from food and air) would have a daily intake of 2.5×10^{-2} µCi and would build up a total body burden of about 0.5 µCi compared with the allowed body burden of about 3 µCi for large populations (the most stringent health case).

Cheaper sources of supply of tritium: if bulk ordering (in the 1000 Ci range), the cost would be reduced to half that quoted in my table.

If we could use somewhat less pure material, including a small content of methyl or ethyl alcohol labelled with labile tritium in the (OH) groups only, then the cost would reduce to between 1/4 and 1/6 of the values in the table, which would give us a very cheap tracer even at 5000 TU."